

Course Outline



EE 2804 – Applied Electricity

B.Sc. Engineering Degree
Semester 3 – 2026 (24 Intake)

Credits :	3
Lecturer :	Prof. Thushara Rathnayaka
Lectures :	2 hours per week
Lab/Tutorial :	2 hours per week
Duration :	14 weeks

Course Details

- 3 credits, GPA
- 80% attendance is compulsory
- Continuous assessments
 - 3 lab experiments
 - 4 Tutorials
 - 2 assignments/quizzes
- Grading
 - 60% from final exam
 - 40% from continuous assessments

Learning Outcomes

After completing this module, the students should be able to

1. Assess the performance of transformers and different electric motors under a variety of load conditions.
2. Select a suitable electric motor for a given application.
3. Describe the application of electrical power in lighting, heating and welding.
4. Apply wiring regulations for domestic wiring and cable selection .
5. Apply cost minimization strategies in the utilization of electric power.

Outline Syllabus

1. Transformers

Single Phase transformers, EMF equation, equivalent circuit & phasor diagram, losses & efficiency, voltage regulation, test on transformers, use of three phase transformers.

2. Induction Motors

Types of rotors and windings, induction motor action, torque speed characteristics, losses and efficiency, starting and speed control, ratings and applications, single phase induction motors and their applications.

3. DC Machines

Equivalent circuits, motor and generator operation, characteristics of series, shunt and compound motors, starting and speed control, industrial applications, brushless DC motors

4. Special Purpose Motors

Universal Motors: constructional and operational characteristics.
Stepper Motors: operation and types, applications.

5. Solid State Control

Introduction to solid state control of dc and ac motors, principles of four-quadrant operation.

6. Electric Lighting

Basic principles, characteristics of light, lamps and luminaires, average lumen method of lighting calculations.

7. Heating and Welding

Heating: heating methods (Joule, induction and dielectric heating), industrial applications.
Electric Welding: types, requirements, welding transformers.

8. Electrical Wiring

Wiring regulations, circuits and wiring symbols, selection and voltage drop calculations of cables, earthing.

9. Economics of Power Utilisation

Cost of Electric Power: fixed, variable and maximum demand charges, tariffs.
Demand Management: power factor correction.

Weekly Schedule

Lec schedule		Tutes
7-Jul	Trasnformers Part I	
14-Jul	Trasnformers Part II	
21-Jul	Trasnformers Part III	
28-Jul	Induction motros Part I	Tute 1 (Transformers)
4-Aug	Induction motros Part II	
11-Aug	DC machines Part II	Tute 2 (Induction motors)
18-Aug	DC machines Part III	
25-Aug	Special purpose motors ; Solid State Control	Tute 3 (DC machines)
1-Sep	In-class test 1	
8-Sep	Electric lighting	
15-Sep	Heating and welding	
22-Sep	Electric wiring	
29-Sep	Economic of power utilization	Tute 4 (Lighting, heating, welding)
6-Oct	In-class test 2	

TRANSFORMERS

References

- “Principles of Electrical Engineering and Electronics”, V. K. Metha
- “Electrical Machinery Fundamentals”, Stephan J Chapman
- “Electric Machinery & Transformers”, Irving L. Kosow

Electrical Machines

Electrical Machines

Static

- Transformers

Dynamic

- Generators & Motors

AC Machines

- Synchronous Machines
- Asynchronous / Induction Machines

DC Machines

- DC Motors
- DC Generators

TRANSFORMERS

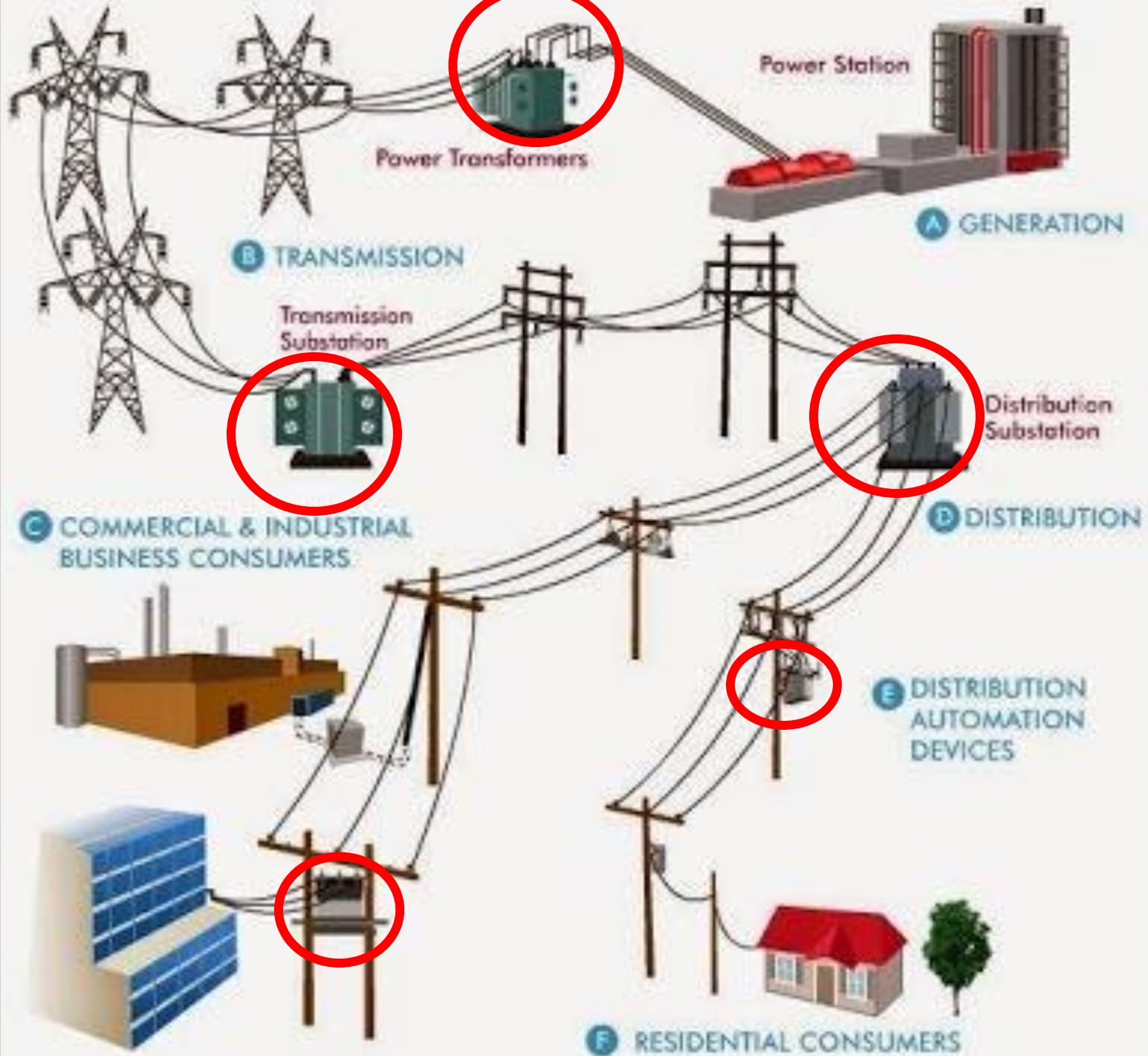
➤ Single phase transformers

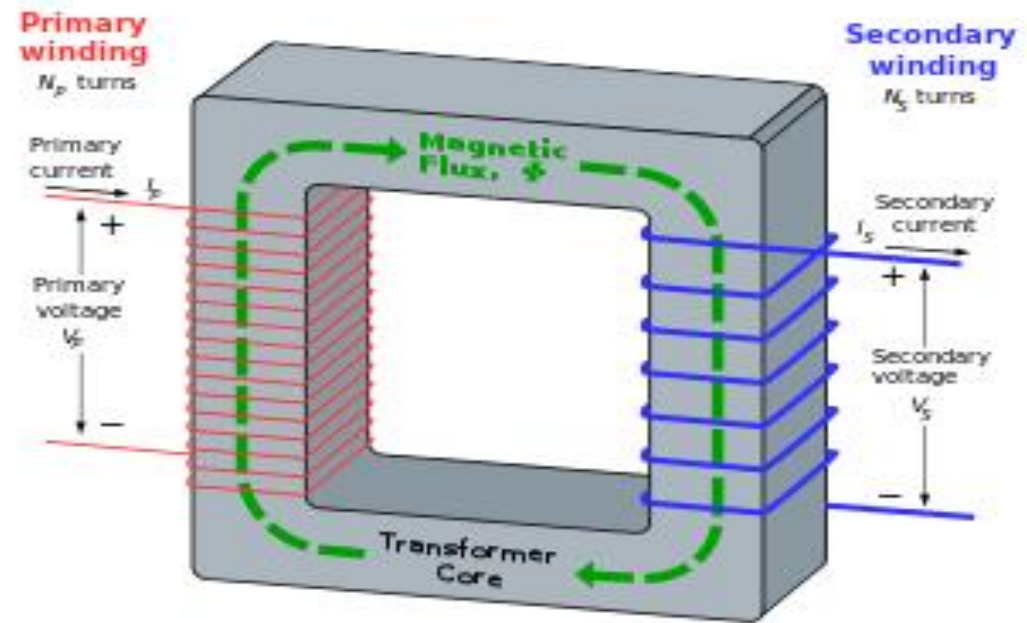
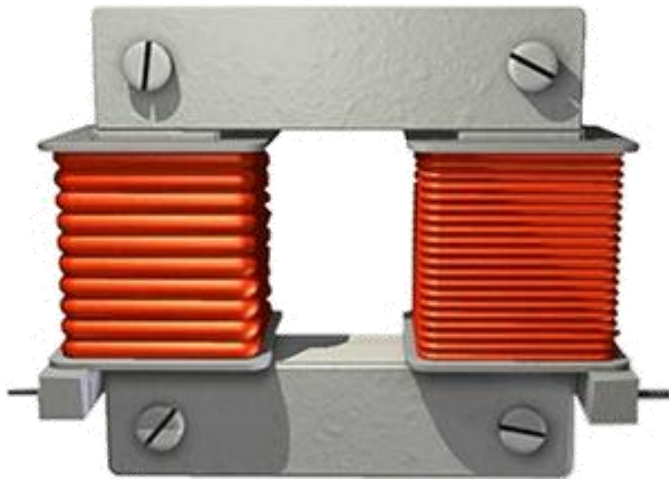
- EMF equation
- Equivalent circuit & phasor diagram
- Losses & efficiency
- Voltage regulation
- Test on transformers

➤ Three phase transformers

Transformers

- Static electrical devices
- Function is to transform an alternating voltage at one level to an alternating voltage at another level without affecting the actual power supplied
- Transformation of voltages is required in both power systems and in electronics
 - Power transmitted at low voltages-> very large currents, huge voltage drops and power losses
 - Semi conductor devices operates at low voltages

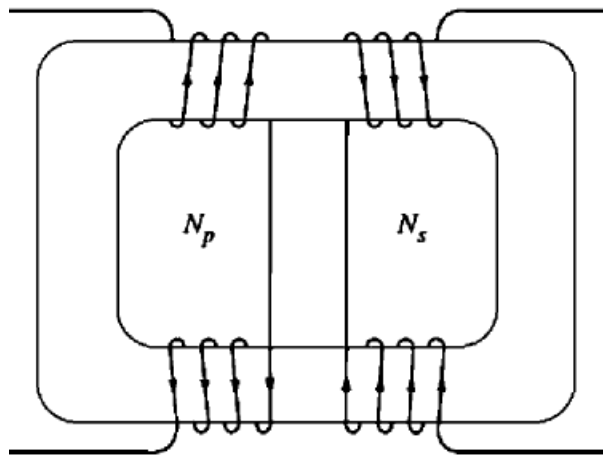




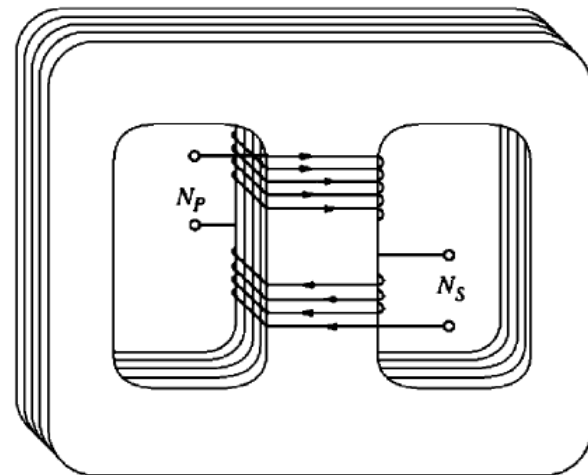
- Two windings
 - Primary winding
 - coil connected to an alternating voltage source
 - Secondary winding
 - delivers power to the load
 - Windings are (usually) not directly connected.
- Magnetic core
 - Magnetic flux, common to both windings

Types and Construction of Transformers

- **Core type:** Windings are wrapped around two sides of a simple rectangular laminated core



- **Shell type:** Windings are wrapped around the center leg of a three-legged laminated core



Primary
Winding

Secondary
Winding



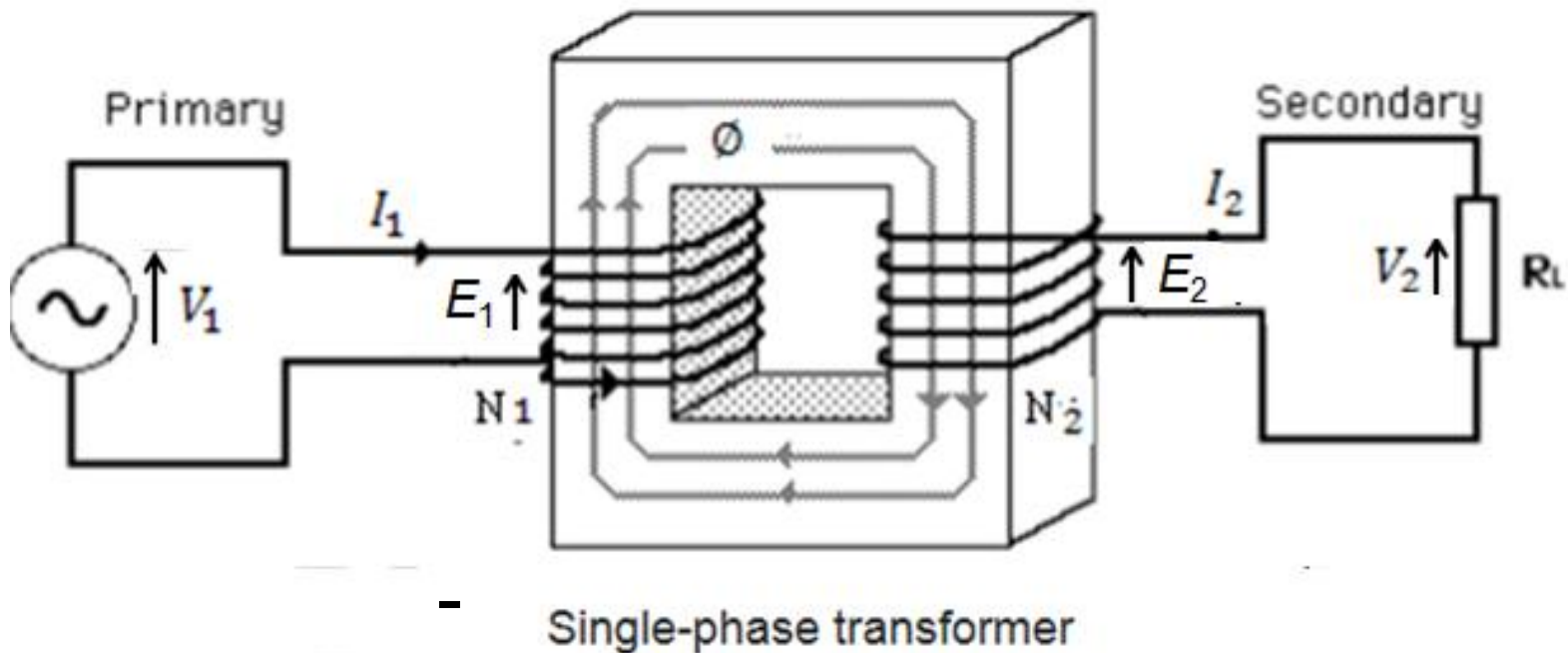
Core Type
Transformer

Primary & Secondary
Winding



Shell Type
Transformer

Principle of Operation



- When an alternating voltage is applied to the primary winding,
 - an alternating current flows through the winding
 - an alternating magnetic flux is produced in the magnetic core
- An e.m.f. will be induced in the primary and secondary windings, according to Faraday's laws and Lenz's law

Faraday's Laws

- Faraday's 1st Law: When the flux linking a conductor or coil changes, an e.m.f. is induced in it.
- Faraday's 2nd Law: The magnitude of the induced e.m.f. in a coil is equal to the rate of change of flux linkages.

Lenz's Law

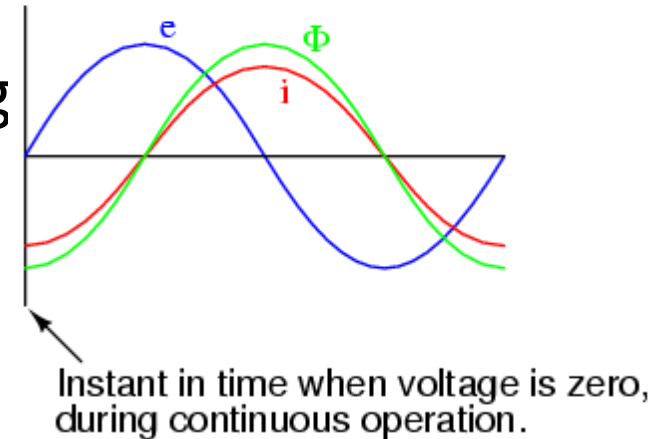
An induced voltage will cause a current to flow in a closed circuit in such a direction that its magnetic effect will oppose the change that produces it.

The Induced e.m.f. in a Coil

- Suppose a coil has N number of turns and the flux (φ) linking with the coil changes.
- According to Faraday's laws and Lenz's law, the induced e.m.f. in the coil,

$$E = -N \frac{d\varphi}{dt}$$

e = voltage
 Φ = magnetic flux
i = coil current



- Current through the primary winding
 $i = I_m \sin(2\pi f t)$

- Flux,
 $\varphi = \varphi_m \sin(2\pi f t)$

- Induced e.m.f in the primary winding,

$$E_1 = -N_1 \frac{d\varphi}{dt} = -2\pi f N_1 \varphi_m \cos(2\pi f t)$$

- Induced e.m.f in the secondary winding,

$$E_2 = -N_2 \frac{d\varphi}{dt} = -2\pi f N_2 \varphi_m \cos(2\pi f t)$$

Therefore, EMF equations of Transformer :

$$E_{1,rms} = \frac{2\pi}{\sqrt{2}} f N_1 \varphi_m = 4.44 f N_1 \varphi_m$$

$$E_{2,rms} = \frac{2\pi}{\sqrt{2}} f N_2 \varphi_m = 4.44 f N_2 \varphi_m$$

Turns ratio,

$$a = \frac{E_1}{E_2} = \frac{N_1}{N_2}$$

Example 1:

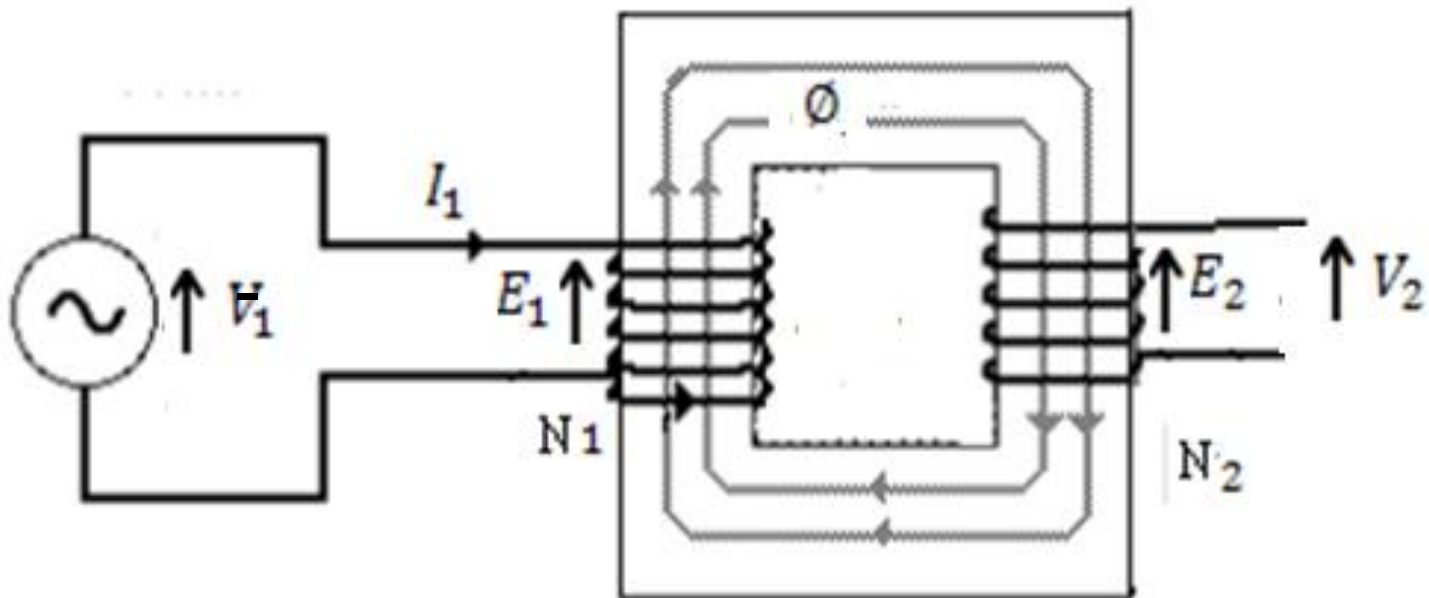
A 230V/12V , 50Hz step down transformer is to be wound on a core of 10.0 cm^2 . The core material has a knee point of 1.6T. Determine the number of turns required for each winding.

Ideal Transformers

(A hypothetical device which only approximate the real device)

Assumptions :

- ▶ Flux produced by the primary winding is fully linked with the secondary winding
- ▶ No losses



- Turns ratio,

$$a = \frac{E_1}{E_2} = \frac{N_1}{N_2}$$

- For an ideal transformer,
 - No voltage drop, $E_1=V_1$ and $E_2=V_2$

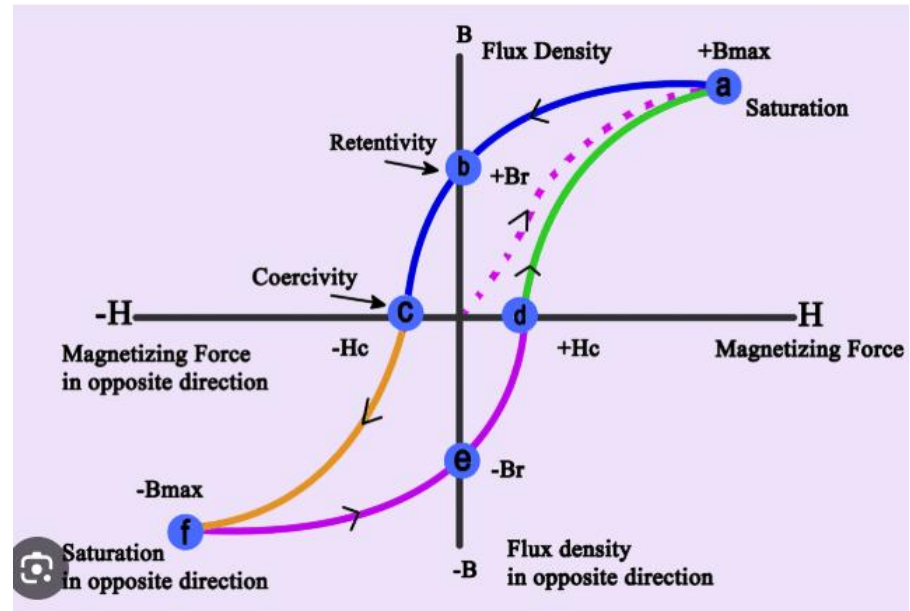
$$a = \frac{E_1}{E_2} = \frac{V_1}{V_2} = \frac{N_1}{N_2}$$

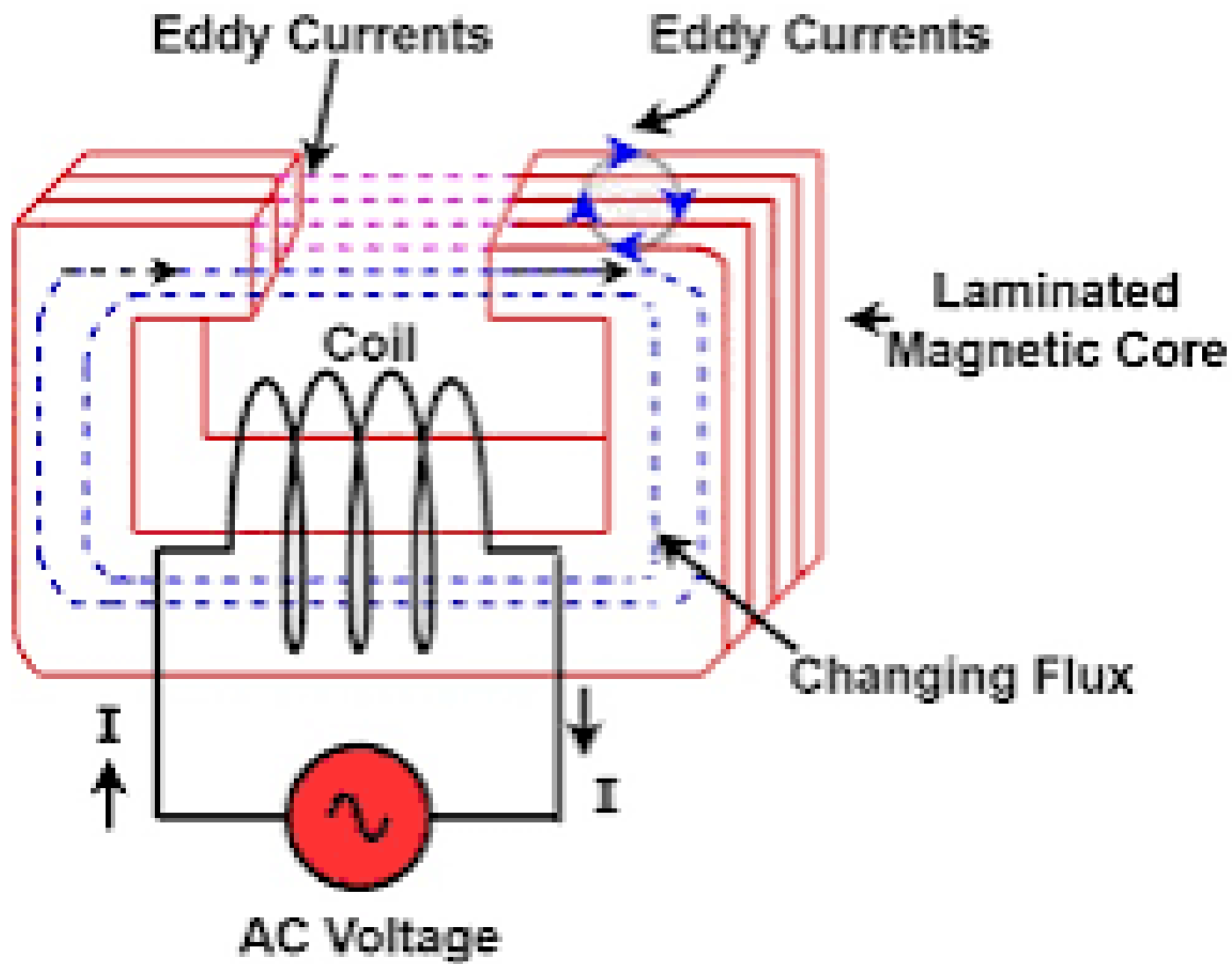
- MMF should be the same, $N_1 I_1 = N_2 I_2$

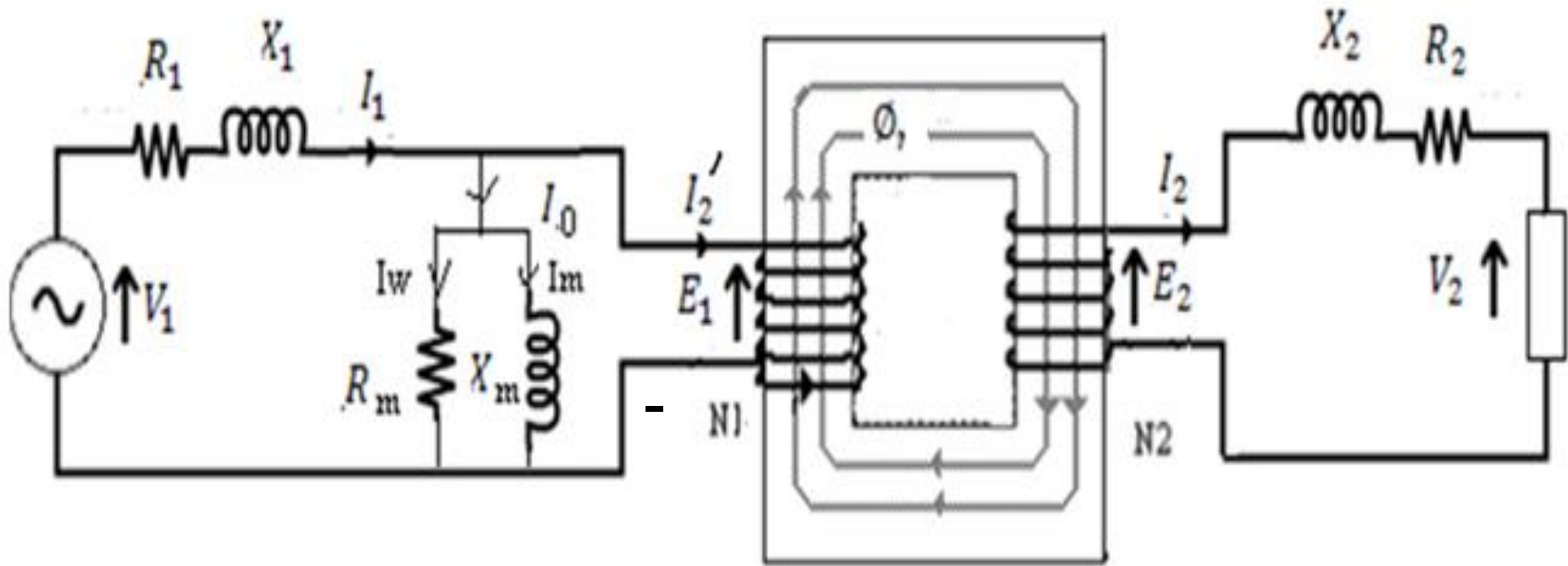
$$a = \frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

Practical Transformers

- Winding resistances
 - Copper losses (P_{Cu})
- Leakage flux : Flux which escape the core and pass through only one of the transformer windings
- Core losses (P_{Core}): due to eddy currents and hysteresis losses

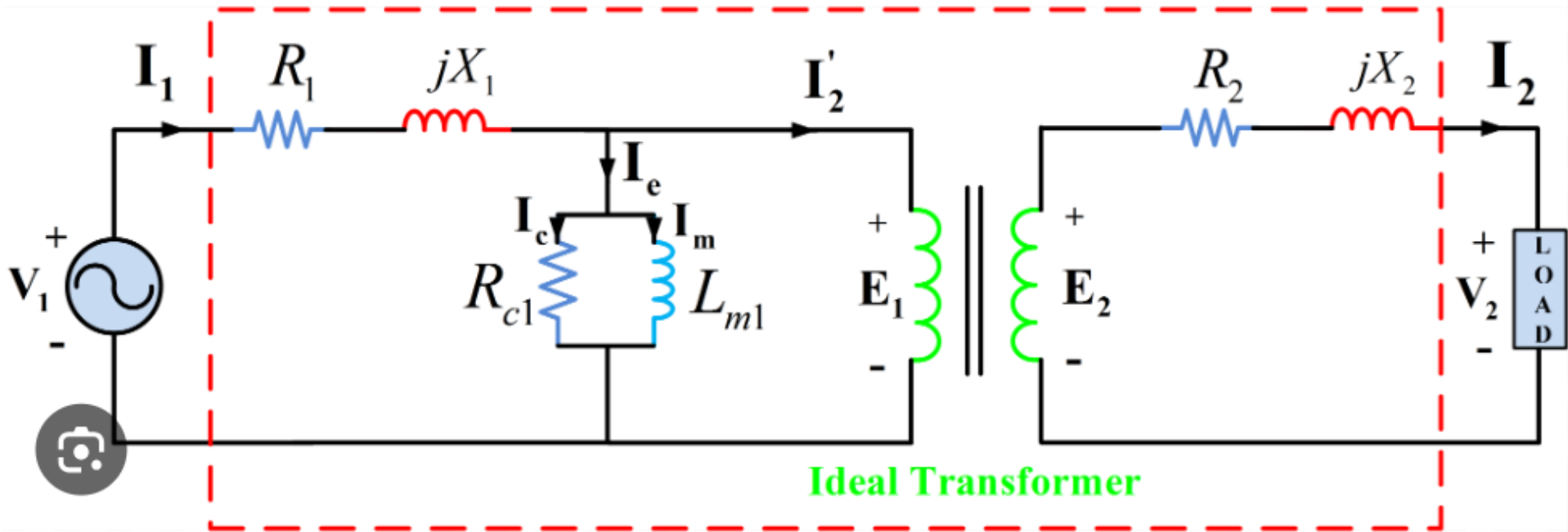






- Winding resistances - R_1, R_2
- Leakage reactances - X_1, X_2
- Core resistance - R_m
- Magnetizing reactance - X_m

- Equivalent Circuit



Shifting Impedances

- ▶ Referred to primary: when secondary R or X (R_2 or X_2) is transferred to the primary it is multiplied by a^2 .
- ▶ Referred to secondary: when primary R or X (R_1 or X_1) is transferred to the secondary it is divided by a^2 .

Eg: Shifting R_2 to primary side:

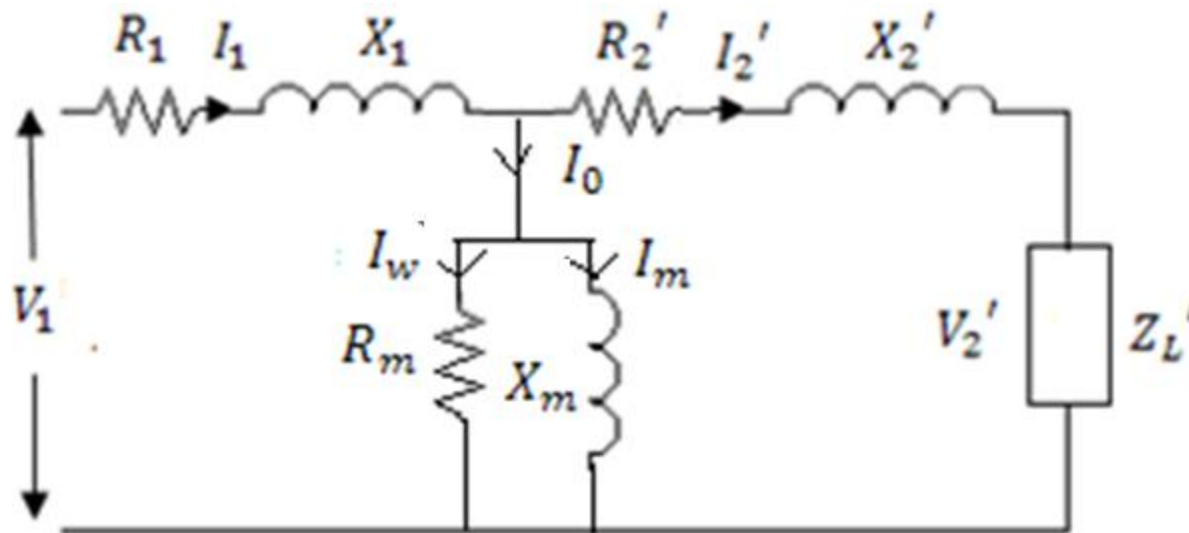
Power losses should be the same.

$$I_1^2 R_2' = I_2^2 R_2$$

$$R_2' = R_2 \left(\frac{I_2}{I_1} \right)^2 = R_2 a^2$$

Equivalent Circuits

- Referred to primary



$$R_2' = a^2 R_2$$

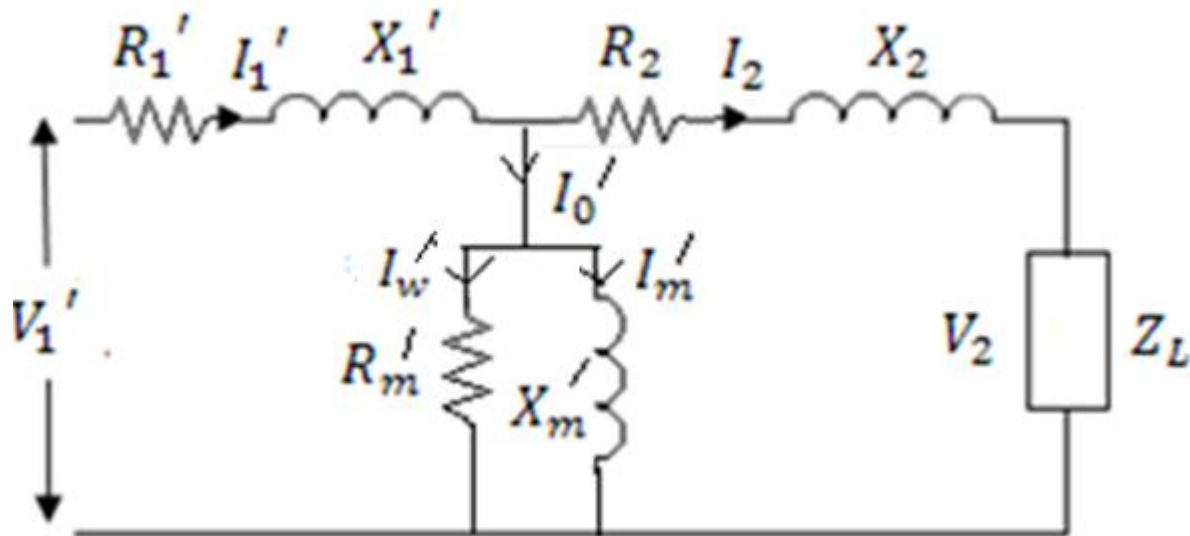
$$X_2' = a^2 X_2$$

$$Z_L' = a^2 Z_L$$

$$I_2' = I_2 / a$$

$$V_2' = a V_2$$

- Referred to secondary



$$R_1' = R_1 / a^2$$

$$X_1' = X_1 / a^2$$

$$I_1' = a I_1$$

$$V_1' = V_1 / a$$

$$R_m' = R_m / a^2$$

$$X_m' = X_m / a^2$$

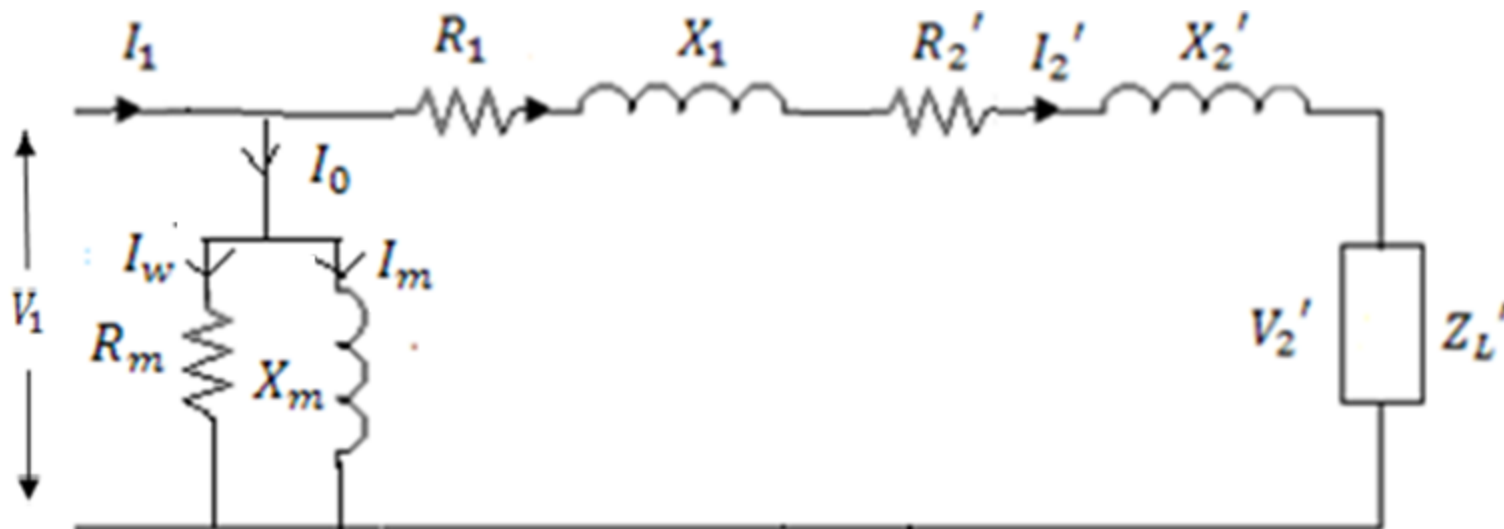
$$I_0' = a I_0$$

$$I_m' = a I_m$$

$$I_w' = a I_w$$

Approximate Equivalent Circuits

- Referred to primary

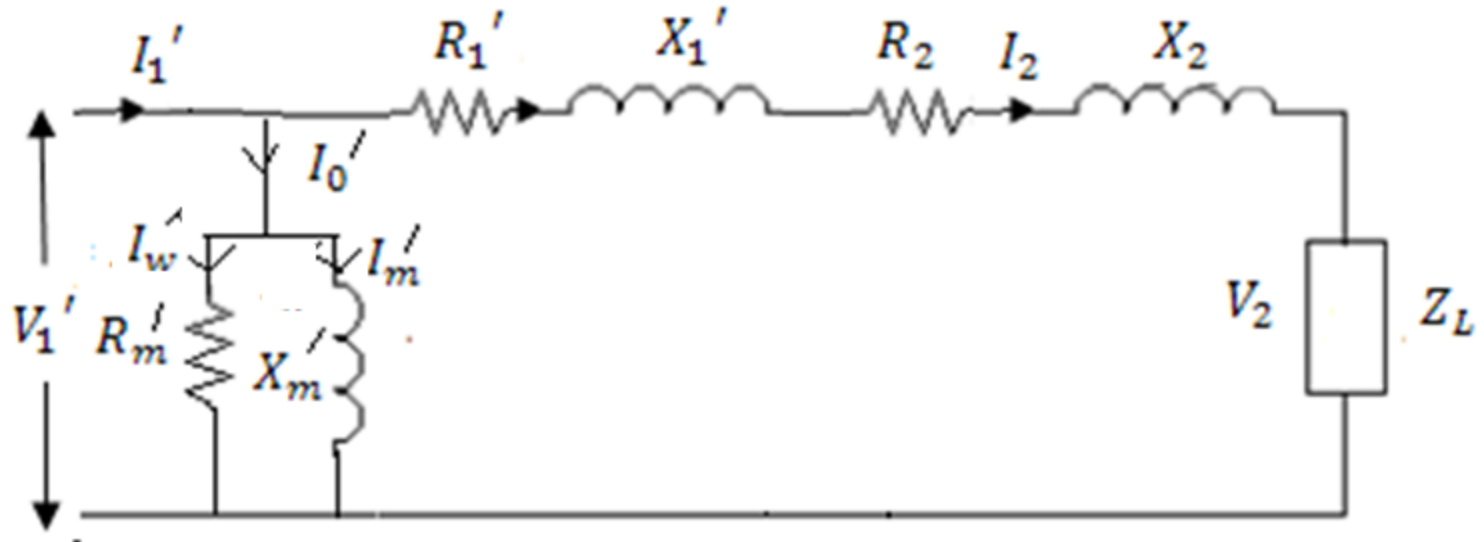


Equivalent resistance and equivalent reactance referred to primary,

$$R_{01} = R_1 + R_2' = R_1 + a^2 R_2$$

$$X_{01} = X_1 + X_2' = X_1 + a^2 X_2$$

- Referred to secondary



Equivalent resistance and equivalent reactance referred to secondary,

$$R_{02} = R_2 + R_1' = R_2 + \frac{R_1}{a^2}$$

$$X_{02} = X_2 + X_1' = X_2 + \frac{X_1}{a^2}$$

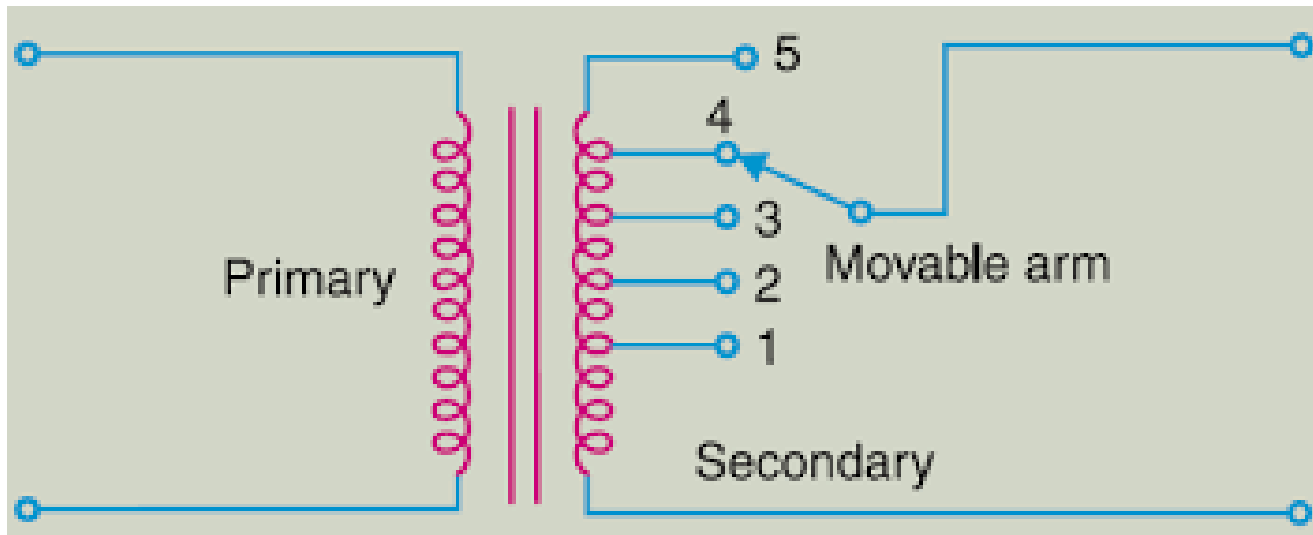
Voltage Regulation

- Real transformer has series impedances, voltage drops
- The output voltage varies with the load even if the input voltage remains constant
- **Voltage regulation:** a quantity that compares the output voltage at no load with the output voltage at full load

$$\text{Voltage regulation} = \frac{V_{2NL} - V_{2FL}}{V_{2FL}} \times 100\%$$

Transformer Taps

- In real distribution transformers,
 - turns ratio is not fixed
 - a series of taps in the windings to permit small changes in the turns ratio
- By adjusting taps, voltage is typically maintained within $\pm 5\%$ of the rated voltage



Efficiency (η)

$$\text{Power Efficiency} = \frac{\text{Output power}}{\text{Input power}} \times 100 \%$$

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

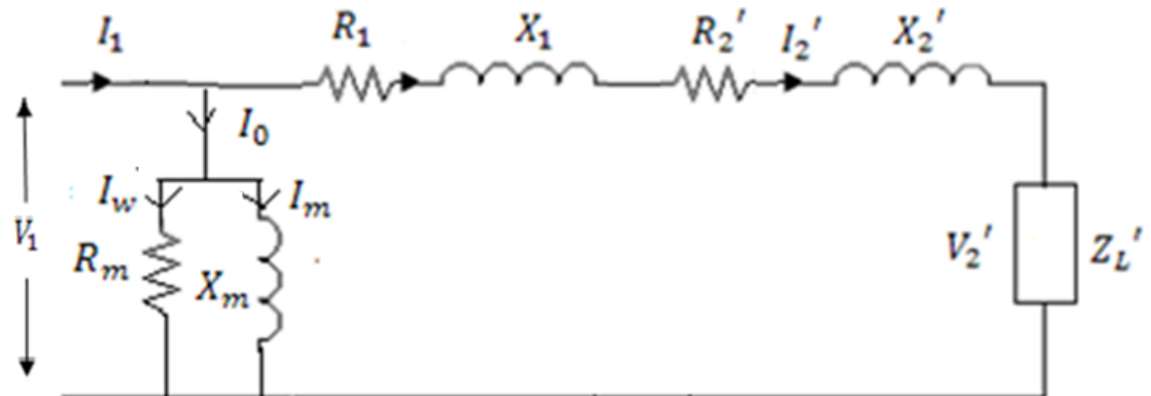
$$\eta = \frac{P_{out}}{P_{out} + P_{losses}} \times 100\%$$

$$\eta = \frac{P_{out}}{P_{out} + P_{Cu} + P_{Core}} \times 100\%$$

$$P_{out} = V_2 I_2 \cos \phi$$

$$P_{Cu} = I^2 R_{eq}$$

$$P_{Core} = I_w^2 R_m$$

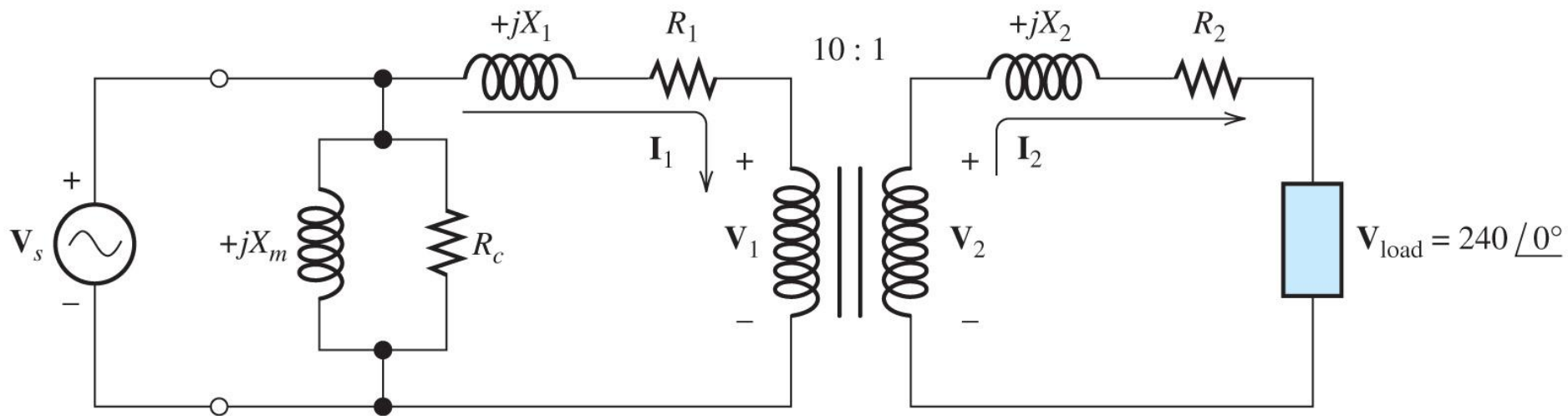


Example 2:

Find the percentage regulation and power efficiency for the transformer of following data for a rated load having a lagging power factor of 0.8. Refer to given figure.

Circuit values of s 60 Hz, 20 kVA, 2400/240 V transformer

Element name	Symbol	Value
Primary resistance	R_1	3 Ω
Secondary resistance	R_2	0.03 Ω
Primary leakage reactance	X_1	6.5 Ω
Secondary leakage reactance	X_2	0.07 Ω
Magnetizing reactance	X_m	15 k Ω
Core-loss resistance	R_c	100 k Ω



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Determining the Equivalent Circuit Parameters of the Transformer Model

Open Circuit Test

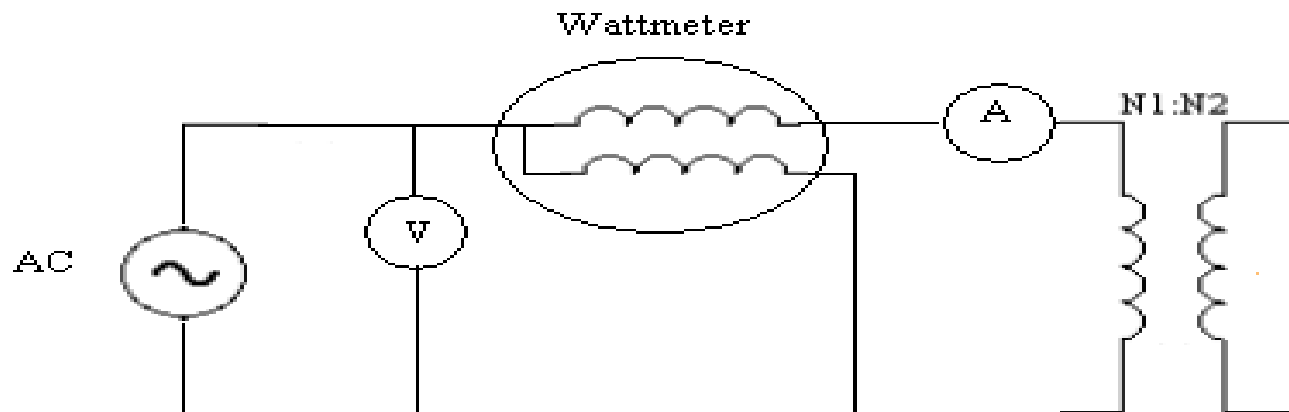
- To find R_c and X_m

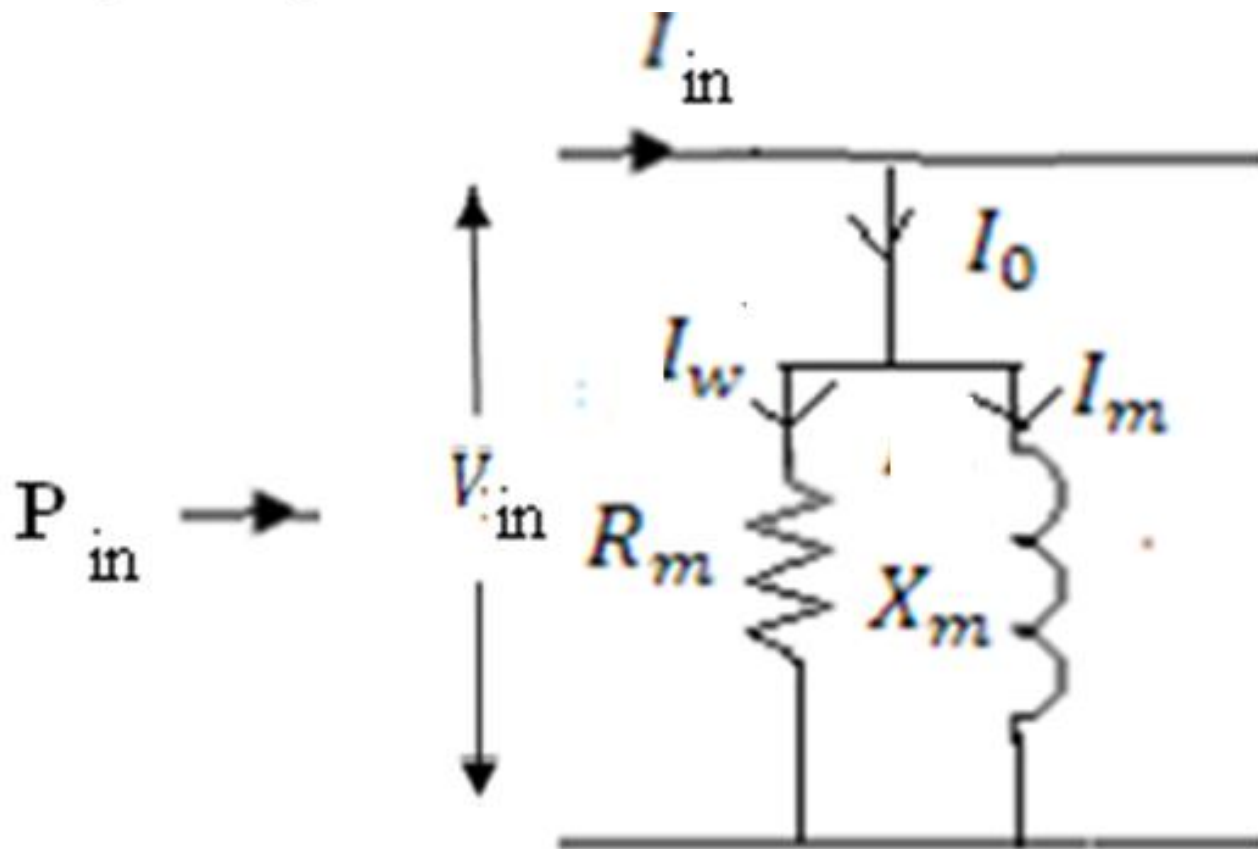
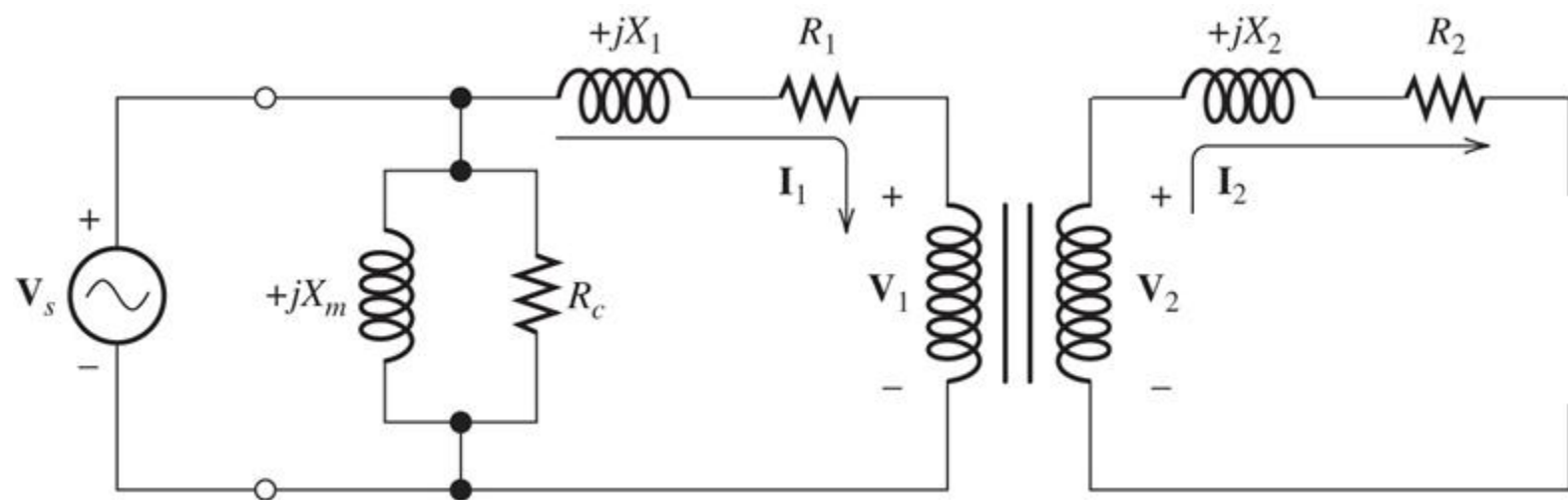
Short Circuit Test

- To find equivalent resistance and equivalent reactance (R_{eq} and X_{eq})

Open Circuit Test

- High voltage winding - open circuited
- Apply **rated voltage** to the **low voltage** side and
- Take ammeter, voltmeter & wattmeter readings at low voltage side.





- Finding R_m

$$P_{in} = I_w^2 R_m = \left(\frac{V_{in}}{R_m} \right)^2 R_m$$

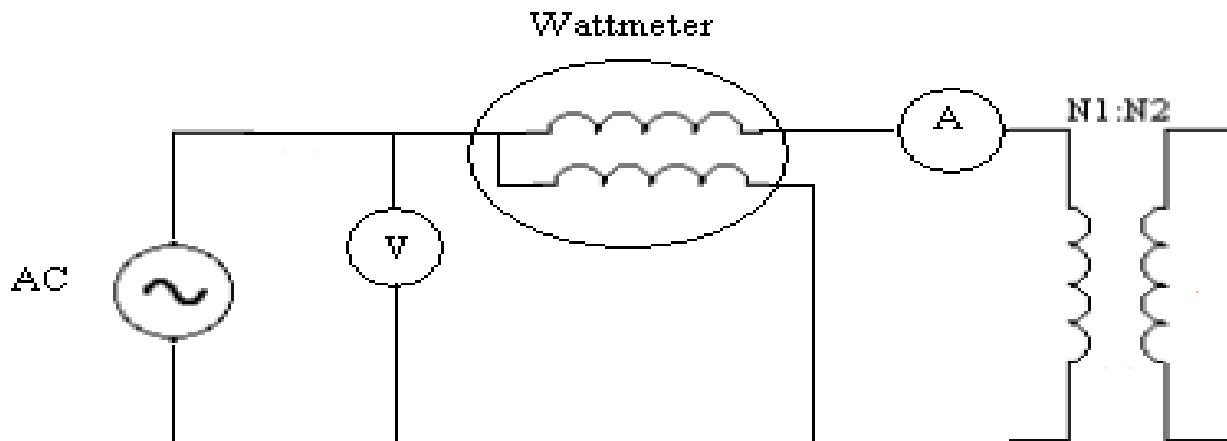
$$R_m = \frac{V_{in}^2}{P_{in}}$$

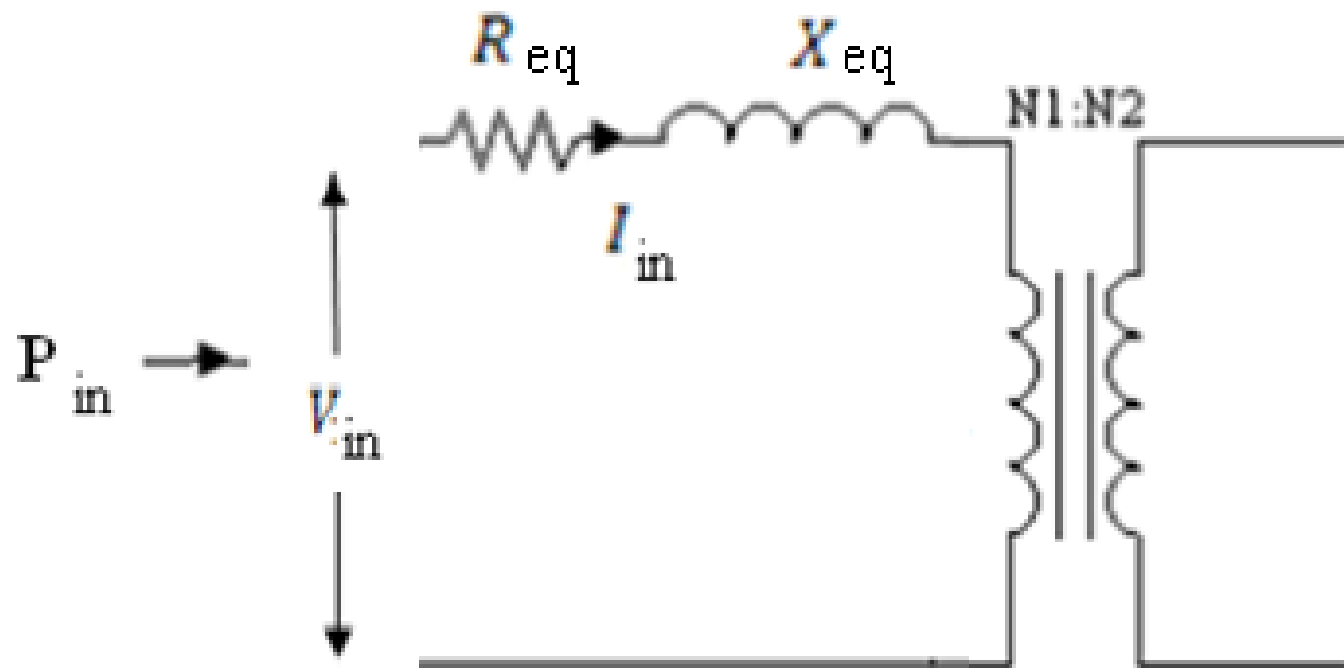
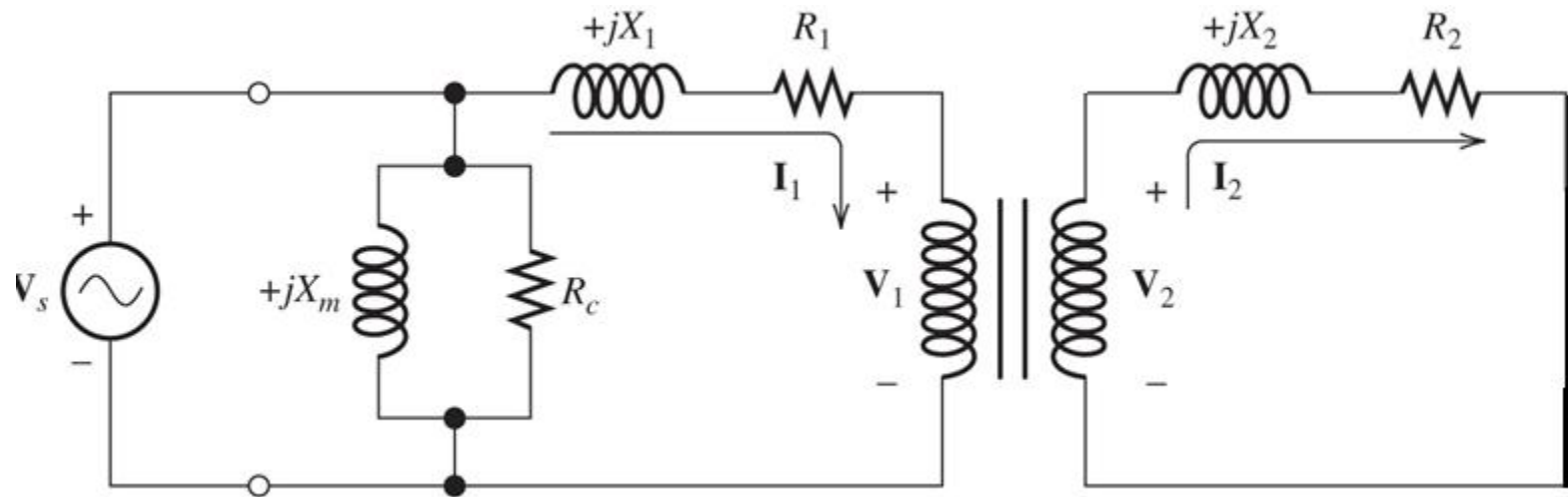
- Finding X_m

$$I_{in} = I_0 = \sqrt{\left(\frac{V_{in}}{R_m} \right)^2 + \left(\frac{V_{in}}{X_m} \right)^2}$$

Short Circuit Test

- Low voltage winding - short circuited
- Apply a fairly low voltage to the high voltage side and adjust this voltage until the **current in the high voltage** windings is equal to its **rated value**
- Take ammeter, voltmeter & wattmeter readings at high voltage side.





- Finding R_{eq}
 - Magnetization current is negligible
 - Copper loss, $P_{in} = I_{in}^2 R_{eq}$

$$R_{eq} = \frac{P_{in}}{I_{in}^2}$$

- Finding X_{eq}

$$\frac{V_{in}}{I_{in}} = \sqrt{(R_{eq})^2 + (X_{eq})^2}$$

Example 4:

The following data were obtained from testing a 48kVA, 4800/240 V step down transformer.

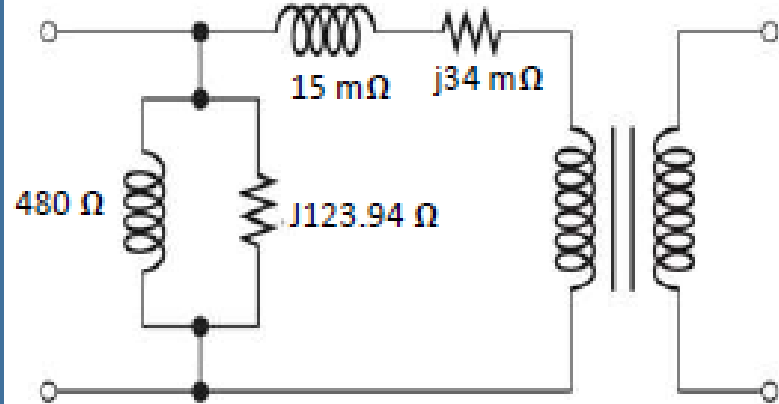
	Voltage (V)	Current (A)	Power (W)
Open circuit test	240	2	120
Short circuit test	150	10	600

Determine the equivalent circuit of the transformer as viewed from

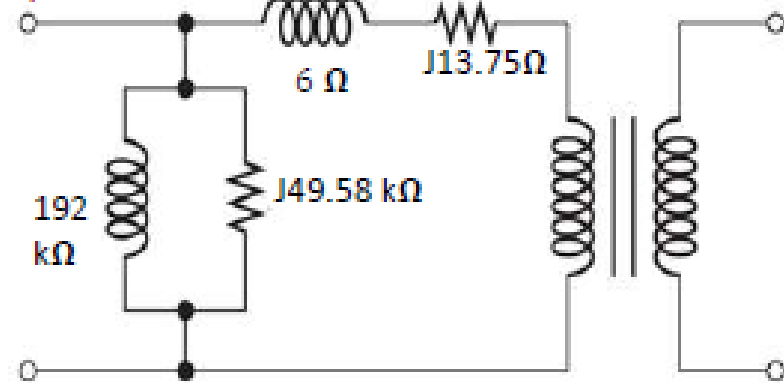
- a) The high voltage side and
- b) The low voltage side

Also draw the exact equivalent circuit.

Equivalent cct viewed from LV side



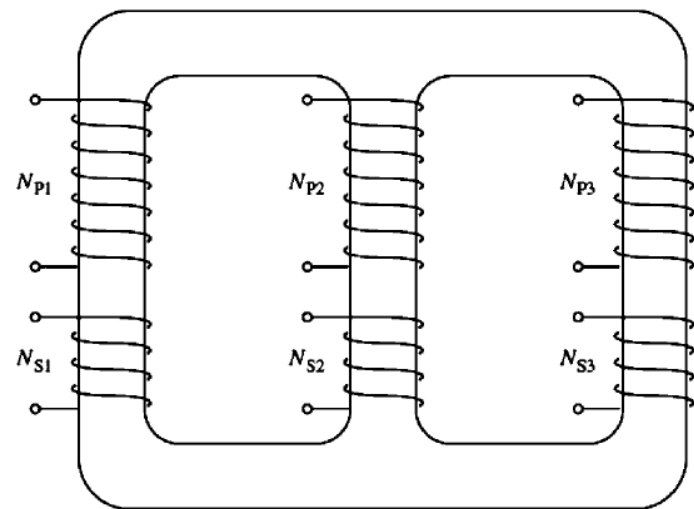
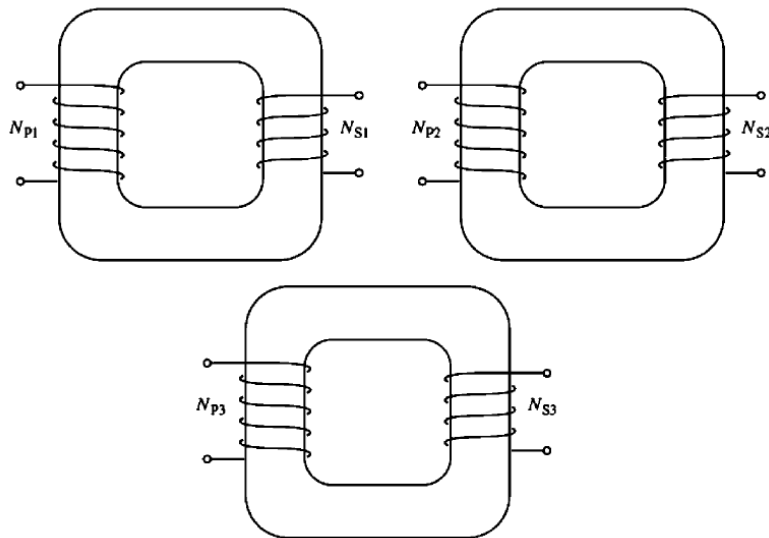
Equivalent cct viewed from HV side



Three Phase Transformers

A three phase transformer can be constructed

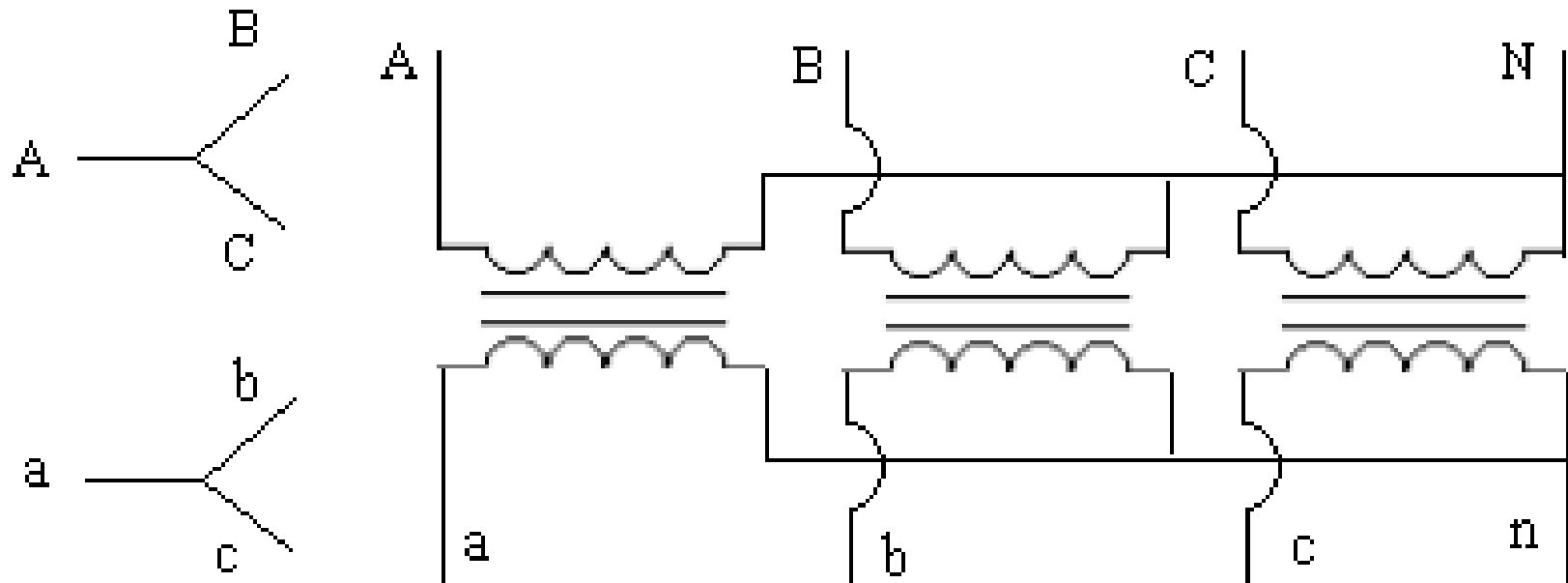
- by connecting three single-phase transformers in a three-phase bank- each unit can be replaced individually
- by wrapping three sets of windings on a common core- cheaper, smaller, lighter, and slightly more efficient



Three-phase transformer connections

- Primary and secondary windings of a three-phase transformer can be connected in either a wye (Y) or a delta (Δ)
- There are four possible connections for a three-phase transformer bank:
 - a) Y - Y
 - b) Y - Δ
 - c) Δ - Y
 - d) Δ - Δ

Y-Y connection

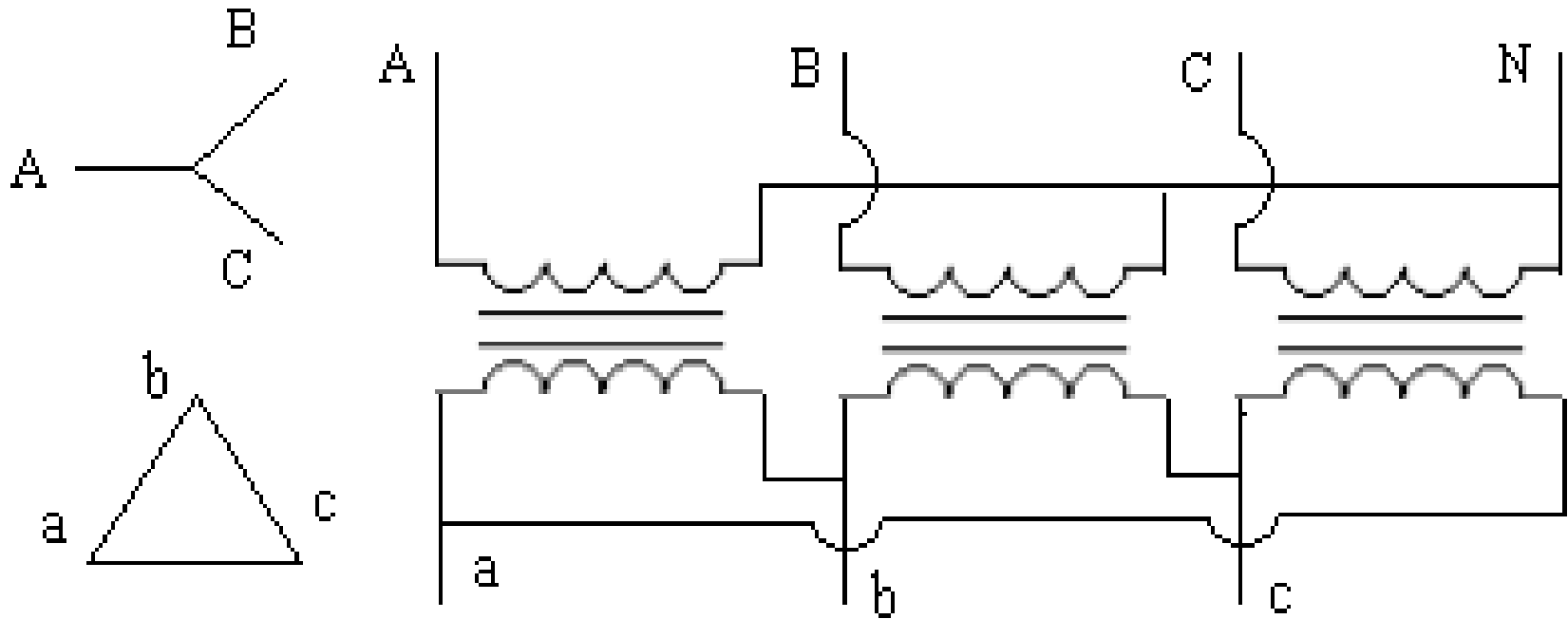


The primary phase voltage, $V_{P1} = V_{L1} / \sqrt{3}$

The secondary phase voltage, $V_{P2} = V_{L2} / \sqrt{3}$

Voltage ratio, $a = V_{L1} / V_{L2} = V_{P1} / V_{P2}$

Y-Δ connection



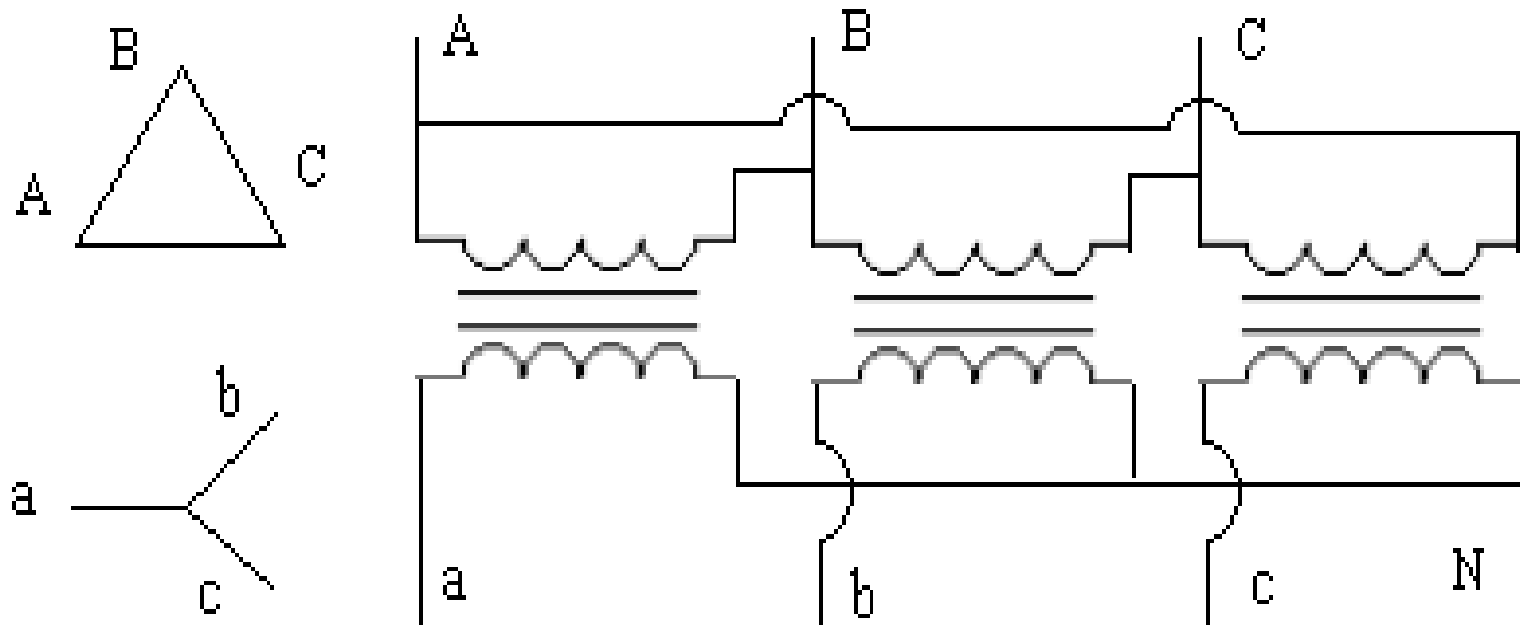
The primary line voltage, $V_{L1} = \sqrt{3}V_{P1}$

The secondary line voltage, $V_{L2} = V_{P2}$

Voltage ratio of each phase, $a = V_{P1}/V_{P2}$

Line voltage ratio becomes, $V_{L1}/V_{L2} = \sqrt{3}V_{P1}/V_{P2} = \sqrt{3}a$

Δ -Y connection

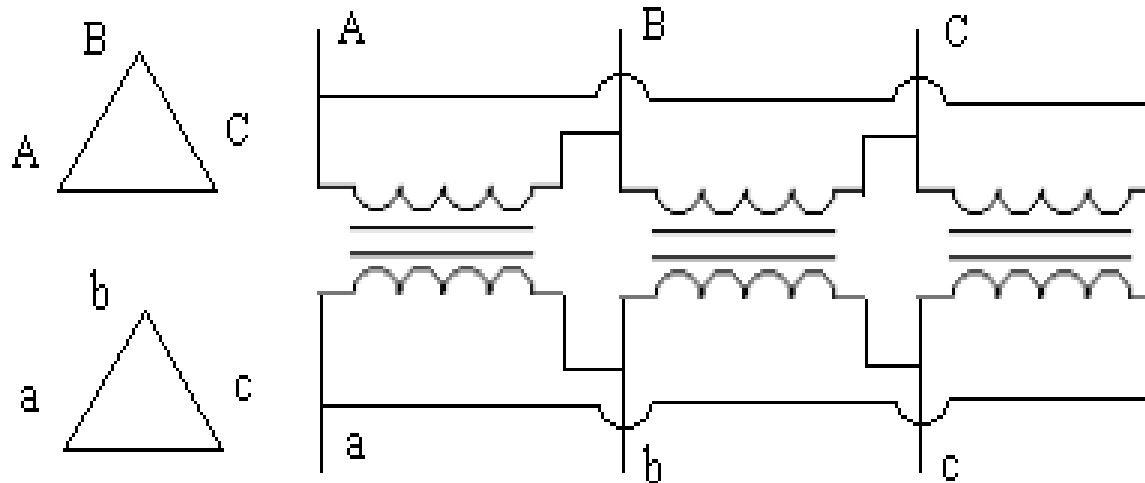


The primary line voltage, $V_{L1} = V_{P1}$

The secondary line voltage, $V_{L2} = \sqrt{3}V_{P2}$

Line to line voltage ratio, $V_{L1}/V_{L2} = V_{P1}/\sqrt{3}V_{P2} = a/\sqrt{3}$

Δ - Δ connection



$$V_{L1} = V_{P1}$$

$$V_{L2} = V_{P2}$$

Line to line voltage ratio , $V_{L1}/V_{L2} = V_{P1}/V_{P2} = a$

Example

A 3-phase, delta/star connected 11,000/440V, 50 Hz transformer takes a line current of 5A, when secondary Load of 0.8 lagging pf is Connected. Determine each coil current and output of transformer

Transformer Ratings & Nameplate

Ratings:

- Rated voltage, rated apparent power, rated frequency, per-unit series impedance, etc ..

Why is it important to mention rated values?

- To protect winding insulations from breakdown due to excessive voltages
- To limit excessive currents and prevent excessive heating
- If operated on a different frequency, voltage should also be changed

$$E_{2,rms} = 4.44 f N_2 \varphi_m$$

References

- “Principles of Electrical Engineering and Electronics”, V. K. Metha
- “Electrical Machinery Fundamentals”, Stephan J Chapman
- “Electric Machinery & Transformers”, Irving L. Kosow